IEA ANNEX 41, SUBTASK 1 – MODELLING PRINCIPLES AND COMMON EXERCISES

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ABSTRACT

The paper gives an outline of existing modelling capabilities as well as an overview of current developments in integral modelling of hygrothermal conditions for whole buildings as presented within IEA Annex 41. Such models deal with the heat, air and moisture conditions of most relevant elements of buildings: The indoor air, the building envelope, inside constructions and furnishing. These building elements interact with each other and they are influenced by the use of the building, the building services, and the outside climate. The transport processes for heat, air and moisture also interact with each other, and everything has an impact on the energy consumption of the building and the quality of indoor air.

A suite of Common Exercises for computational modelling are developed and executed within this modelling subtask. The common exercises test the current capabilities of existing models and, very importantly, they stimulate the development of new models or the expansion of capabilities of existing models. The first two Common Exercises have been executed already. Some further plans for the subsequent Common Exercises will be outlined in the paper.

KEYWORDS

Heat, Air, Moisture, Whole buildings, Modelling

INTRODUCTION

Annex 41 of the International Energy Agency's (IEA) Energy Conservation in Buildings and Community Systems programme (ECBCS) is a cooperative project on "Whole Building Heat, Air and Moisture Response". The project seeks to deepen the knowledge about the integrated heat, air and moisture transport processes when the whole building is considered. That means it is necessary to consider all the elements: the separate building materials, the composite constructions, furniture and the indoor climate with its users, systems for heating, cooling and air-conditioning, as well as the outdoor climate. All these elements have an effect on each other. Also, the nature of the transport processes for heat, air and moisture (HAM) make them depend on each other. While research projects in the past have been focusing only on some of these elements at a time, Annex 41 seeks to develop further understanding of how the elements function together. This will be done by concerted actions which seek to further and develop the common experiences in modelling and experimenting on the involved topics. Elementary processes which have also been studied in the past, such as moisture transport in materials, or wind-driven rain on facades are also studied in the Annex, but only with the objective to study how such processes influence the whole building performance.

The four-year project started in November 2003 and has succeeded to gather significant international contributions from researchers of four continents in the world. Altogether researchers from some 39 institutions representing 19 different countries participate in the project. The project has the two homepages: http://www.ecbcs.org/annexes/annex41.htm (hosted by the IEA ECBCS programme), and http://www.kuleuven.be/bwf/projects/annex41/ (by the project's Operating Agent, the Catholic University of Leuven, Belgium).

This paper focuses on activities in the IEA Annex' Subtask 1: *Modelling Principles and Common Exercises*. Other subtasks are: Subtask 2 - *Experimental Investigations*; Subtask 3 - *Boundary Conditions*; and Subtask 4 - *Long Term Performance and Technology Transfer*.

MODELLING OF HYGROTHERMAL CONDITIONS IN WHOLE-BUILDINGS

Traditionally, computational models that cover the whole building have been focusing mainly on the thermal aspects, since this has been complicated enough to cope with for all the different building elements, the HVAC systems, and the users. Today however, although some developments are still ongoing, this kind models have been quite well established for at least one decade. On the other hand, models which deal with several processes, such as the flow of heat, air and moisture have mainly been focussing on one building element at a time. Such models have also been reasonably well established for about one decade.

However, it is well known, that the different hygrothermal processes interact with each other: E.g. moisture conditions cannot be predicted without knowledge about the thermal state, mass flows such as by air or moisture also have and impact on the thermal conditions, and air flows may severely impact the moisture behaviour. Likewise, the hygrothermal conditions in individual building components interact importantly with the indoor climate they surround. One could not predict the conditions in the envelope of building without knowing or assuming something about the indoor conditions, and those indoor conditions are, among other things influenced by the building elements.

Today we have begun to see the development of models that cope with these issues in an integrated way. Subtask 1 of IEA Annex 41 seeks to stimulate this development. Obviously, there are three possible ways to approach the whole building HAM simulation:

- To improve existing building simulation tools so they can better account for processes linked with the envelope,
- Extension of building component simulation tools,
- A combination of both building simulation and building component simulation tools.

Generally, the models used are either hygrothermal models for components of the building envelope which are expanded with models for indoor air volumes and by making provision for simultaneous calculation of several building components – e.g. Holm et al. (2003). Alternatively, building energy simulation models, which already have capabilities for making thermal analysis of whole buildings, are expanded with models for transient moisture transport in the building components - e.g. Rode & Grau (2003).

The mission of IEA Annex 41's Subtask 1 is to stimulate this development by inspiring the research work and gathering the experiences. To qualify as an IEA Annex 41 contribution, research work, including modelling, must comprise at least two of the processes: Heat, Air and Moisture, and it must comprise building elements on various levels from the individual building material to the whole building.

The Annex also invites more fundamental research contributions from the participants as long as they relate to the overall subject of the Annex. Such research is presented in so-called "free papers", and there has until today been free papers on subjects such as: CFD-models for air-moisture transport in rooms; analytical solutions; toolboxes such as MATLAB; sensitivity studies on energy effects; zonal approaches; algorithm development; material–air interaction; and case studies. Further free papers are invited particularly within the nominated topics: Sensitivity studies; convective vs. heat and moisture flows (e.g. by CFD); surface coefficients; integration aspects; simplified models; multidimensional effects; integration of systems; energy impacts.

COMMON EXERCISES

The purpose of the common exercises being part of Subtask 1 of the Annex is to test the possibilities of the existing models or models under development to predict the integrated hygrothermal behaviour of buildings and to stimulate new development in this area. Besides this, common exercises provide elements of validation of HAM building simulation tools. The following elements necessary for code validation will be included in common exercises:

- analytical verification
- empirical validation vs experimental data
- finally comparative testing, which is the heart of all the common exercises.

As of to date the following Common Exercises (CE) have been executed as part of Subtask 1 of Annex 41:

- Common Exercise 0 (CE0). Validation of thermal aspects of the employed models. This was done by repeating the building energy simulation test BESTEST of IEA SHC Task 12 & ECBCS Annex 21 (Judkoff and Neymark, 1995).
- Common Exercise 1 (CE1). Expanding on CE0 and the BESTEST case by adding considerations about moisture interactions between building constructions and indoor climate.

Both these exercises study the IEA BESTEST building. The IEA BESTEST building is also referenced in ASHRAE Standard 140 (ASHRAE, 2004). The building shown in Figure 1 has a simple structure with two windows facing south. It is superficial, so no measurement data exist. The cases serve to provide comparison between different modelling results.

Along with the numerical results, reports on the program and modelling choices were filled in by the participants. These reports contribute to the documentation of the state-of-the-art of models that can be used for whole building heat, air and moisture transfer simulations.

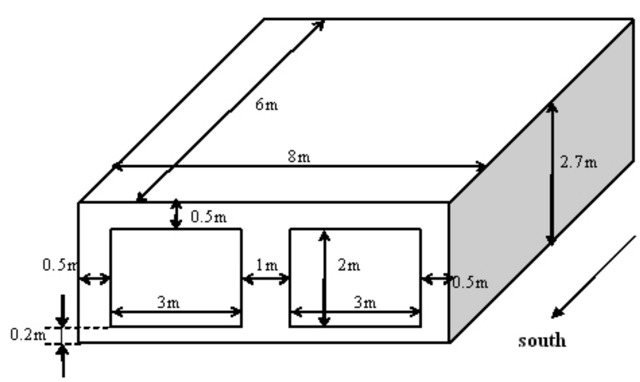

Figure 1 BESTEST base case building.

CE 0 Thermal Building Simulation

For the purpose of Annex 41, four cases where chosen from the original BESTEST procedure, adapted for whole building approach, including a lightweight building and a heavyweight building. There were also cases with free floating thermal conditions as well as cases with active heating and cooling systems. More information on the cases is given by Judkoff and Neymark (1995).

13 sets of results were collected coming from 11 institutions from 9 countries using the following different programs: *BSim*; *Clim2000*; *EnergyPlus*; *ESP-r*; *HAMLab*; *HAMTool*; *IDA ICE*; *ITT DELPHIN*; *TRNSYS*; *Wufi+*. The programs participating in CE0 are both public domain and commercial software, and their common feature is continuous development of physical models. Different solution methods are used in these models, such as explicit and implicit finite difference algorithms, or response factor type methods. Both fixed and auto-adaptative time steps are equally represented. Also, the reconstruction of outdoor climate from meteorological data varies. Some programs use linear interpolation while the others assume that the climate remains constant over the sampling interval. All models used include moisture in the balance of the air zone, but at the time of executing CE0 only a few programs represented moisture transfer through the envelope.

CE 1 Hygrothermal Building Simulation

Common Exercise 1 expanded on Common Exercise 0 by adding the indoor and building envelope moisture conditions for the BESTEST building used in CE0. The first results of the Common Exercise 1 showed, however, that the original case had too many uncertainties even within the thermal calculation, e.g. the presentation of the material data, window models etc. Therefore, a step back was taken with Common Exercise 1A (an analytical case) and Common Exercise 1B (a more “realistic” case). The constructions were made monolithic, the material data were given as constant values (CE1A) or functions (CE1B) and the solar gain through windows was modelled simplified.

Altogether 16 institutions participated in at least some parts of Common Exercise 1. The tools used were: *1DHAV+*; *BSim*; *Clim2000*; *EnergyPlus*; *Esp-r*; *HAMLab*; *HAMTool*; *HAM-VIE*; *IDA ICE*; *ITT DELPHIN; NPI*; *PowerDomus*; *SPARK*; *TRNSYS*; *Wufi+*; and *Xam*; Some of the institutions have used the same code for all the exercises – with or without modifications from case to case – while others have used 2 different codes or have not taken part in a single exercise.

Conclusions to Draw from the Common Exercises

The Common Exercises 0 and 1 stimulated some developments of different software as well as some original use of existing programs. They also showed that there is a need for some consensus data concerning heat and moisture properties of the materials. In the following, some experiences from the exercises are discussed. Attention is paid both to the new achievements and to the problems that occurred.

CE 0 (Heat)
Common Exercise 0 stimulated some improvement of existing programs, namely concerning the “H” (Heat) part of HAM-models, and specially radiation heat transfer calculations. Both

short wave radiation (computation of incident solar radiation and heat gains through the windows) and long wave intra-zone exchanges were enhanced in some programs. As heat, air and moisture closely interact with each other in a building, a correct description of energy behaviour is needed before assessing whole building moisture performance.

The deviation of results within a reasonable range gives also some more confidence in energy models and provides a valuable reference case for some future sensitivity study on the impact of moisture on energy loads.

CE 1 (Heat and Moisture)
The results from the original case (CE1) showed however that now there was not even agreement in the way the models calculated the thermal conditions. However, one should be reminded that this was a first attempt ever of trying to compare the results of this kind of models with moisture.

It was concluded after presentation of these results that the exercise should be redesigned to become significantly simpler in order to avoid deviations due to factors that are not central for the hygrothermal modelling itself.

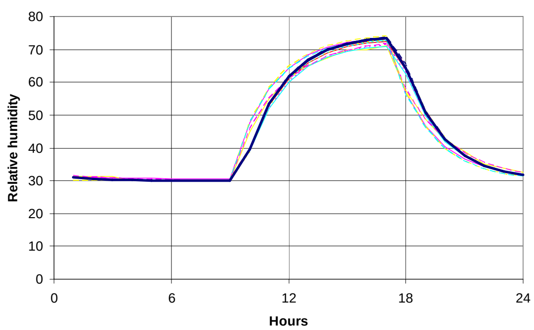

Figure 2: CE1A. Indoor relative humidity. Isothermal exposure. Construction surfaces are tight. The numerical results are compared with the analytical consensus solution.

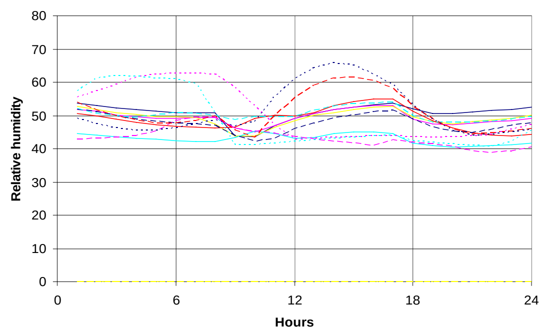

Figure 3: CE1B. Indoor relative humidity. Non-isothermal conditions and open surfaces. A day in July with solar and long wave radiation through the windows and on external opaque surfaces.

The first part of the revised exercise (CE1A), was a very simplified isothermal case with tight or open indoor surfaces, which showed very good agreement between both the analytical solutions and the numerical calculations (see Figure 2). These results gave an increased belief that it was possible to predict the indoor RH with a whole building hygrothermal calculation. However, in this case some important building elements like windows were neglected.

The second and more realistic part of the revised exercise (CE1B) illustrated again the complexity of the whole building hygrothermal modelling: New deviations could not be neglected. The differences in the thermal calculation could not fully explain the deviations as they occurred also for the case with constant indoor temperature. Figure 3 illustrates the variation in the resulting indoor RH for the case where the solar and long wave radiation were included.

FURTHER WORK

The experience from the Common Exercises so far tells that there is a need to execute more cases, especially with comparison with measurement data. Also adding furniture to the set-ups and considering the air flows has to be considered as well.

The actual challenge in whole building Heat Air and Moisture modelling is to develop good paradigms for modelling the correspondence between the numerous different and physically coupled phenomena rather than to develop new models where the elementary processes are dealt with separately. Another important issue is the relative importance of different phenomena and their interactions. Sensitivity analysis and the future common exercises should help to answer the fundamental question when and which interactions can be neglected and in which cases they must be represented. The plan for further exercises is as follows:

- CE 2: Based on experimental data from climate chamber tests at Tohoku University, Japan. The tests have known wall claddings and air flow conditions.
- CE 3: Based on double climatic chamber tests carried out by the Fraunhofer Institut für Bauphysik, Germany, using two identical chambers with different cladding materials.
- CE 2007. A two-storey climatic chamber test carried out at Concordia University, Canada, will serve as basis for this exercise.
- CE “X”. Based on data from a real life row house located in Belgium. with some known indoor climate/moisture problems which also involve effects of adventitious airflow.

GENERAL CONCLUSIONS

The Common Exercises executed as a part of the Annex 41 Subtask 1: Modelling have illustrated the complexity of the whole building hygrothermal modelling: It was possible to find a consensus among the solutions with different calculation models only for an extremely simple isothermal case - a building with monolithic walls and without windows.

On the other hand, these results also underline the importance of this type of exercises: The existing codes are “tested” for their suitability for the whole building hygrothermal simulation and the new ones are created, including upgrading and developing the existing codes to be able to handle also the moisture calculations.

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